THE MONTEPORZIO TWO METER AMPLITUDE INTERFEROMETER

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ABSTRACT

The two meter baseline interferometer of the Royal Observatory, Edinburgh, will be described. This instrument was designed specifically for the observation of binary stars which have angular separations intermediate between the classical visual binaries and spectroscopic systems. Observations on bright stars suggest that it should be possible to measure the fringe visibility with an accuracy of a few percent.

1. INTRODUCTION

The two meter stellar interferometer was designed and built by R. Q. Twiss specifically for the study of visual binary stars. The project was supported and funded by the Royal Observatory, Edinburgh, and the interferometer was sited at the Observatory's outstation at Monteporzio Catone, near Rome, Italy Unfortunately the station was closed in 1977, and the future of the interferometer is uncertain. A preliminary report on the instrument was presented at the I. A. U. Colloquium No. 33 on the observational parameters and dynamical evolution of multiple stars.[1]

A stellar interferometer with a baseline of only two meters has a limiting resolution of about $0\overset{''}{.}01$, which is rather low, especially when it is compared with the resolution attainable with some of the instruments which have been described by other participants at this Colloquium. Nevertheless the interferometer is ideally suited for the investigation of binary star systems that lie in the gap between classical visual binaries and spectroscopic doubles. These systems, which can be expected to have periods of the order of a few months to about a year or so, are difficult to observe by conventional techniques, mainly because of the limitations imposed by "seeing."

The data obtained from observations in this range can be used for a number of purposes, the most important of which are: (a) the determination of the absolute distance to the source (dynamic parallax); (b) the estimation of the mass of the system and, under favorable conditions, the component masses; and, (c) general studies of the structure and evolution of binary systems. The first of these applications requires that the star be a double-lined spectroscopic binary, but it is extremely rare for such a star to have an angular subtense greater than 0".01. The second application ideally requires that the star be spectroscopic, but the system mass can be found if the trigonometric parallax is known. As there is an uncertainty of ∿0".01 in parallaxes,[2] one is basically restricted to stars with parallax greater than about 0".05 (i. e., closer than 20 parsecs). There are only about 250 of these among the stars brighter than magnitude 6.5.[3] The third item on our list differs from the others since here one is concerned chiefly with filling out the statistics of binary star distributions, and a knowledge of the period and apparent semi-major axis (in arcseconds), as well as spectral type, is sufficient. It is for this last type of research that the Monteporzio interferometer is most useful. As a "dedicated" instrument it can be employed for the extensive, time-consuming observing programs that are necessary. The interferometer is thus complimentary to techniques such as speckle interferometry which are used with large telescopes to obtain diffraction limited resolution. Because of the inevitable restrictions on observing time such techniques seem best suited for the study of the specific systems covered by (a) and (b) above, for which one may hope to gain astrophysically meaningful data in a relatively short time.

2. DESCRIPTION OF THE INTERFEROMETER

Because of the relatively short baseline of 1.87 meters it became possible to mount the entire interferometer on a large azimuth platform. This platform, in the shape of a T, is a massive casting and is rotated by means of a precision rotary table and a d. c. servomotor This configuration has a number of advantages; in particular the baseline can be kept normal to the line of sight to the star, greatly simplifying the problem of path compensation. A drawback of this design is that since the projected baseline is always fixed, only one point of the coherence function can be measured, so that the interferometer cannot be used to make reliable observations on centrosymmetric objects. On the other hand, with binaries the fringe visibility is modulated with time because of the relative rotation of the star with respect to the baseline. The correlation is given by Eq. (1):

$$\Gamma^2(\psi) = (1 + \beta^2)^{-2}\cdot\{1 + \beta^2 + 2\beta\cos[2\pi\theta_0 D\cos(\psi)/\lambda]\} \quad , \qquad (1)$$

where $\beta \geq 1$ is the brightness ratio of the two components, θ_0 their angular separation, ψ the relative position angle, D the baseline length and λ the operating wavelength, equal to 442 nm. The angle ψ is equal to the sum of the true position angle ϕ of the star and the parallactic angle η. This latter quantity is a known function of the hour angle and for stars which transit near the zenith it changes very rapidly. As a result, θ_0 and ϕ can be quickly and accurately determined.

The use of an azimuth platform obviates the need for the usual dynamic path compensation. The penalty paid for this is that the platform must be accurately guided: an error of 1" is equivalent to 10 μm of path difference for a two meter baseline. The azimuth and elevation motors are driven at the correct rates by means of a desktop computer,[4] and autoguiders are used to remove the residual tracking errors.

Figure 1 (overleaf) shows the basic optical configuration of the interferometer. Elevation flats (E) are used to direct starlight into both the interferometer proper and the guide optics, consisting of the telescopes T_g and the "optical pyramids" (py) which serve as quadrant detectors. The flats must be accurately coplanar at all elevation angles to avoid path errors; auxiliary interferometric techniques were used to obtain coplanarity with an accuracy of about ±25 μm.

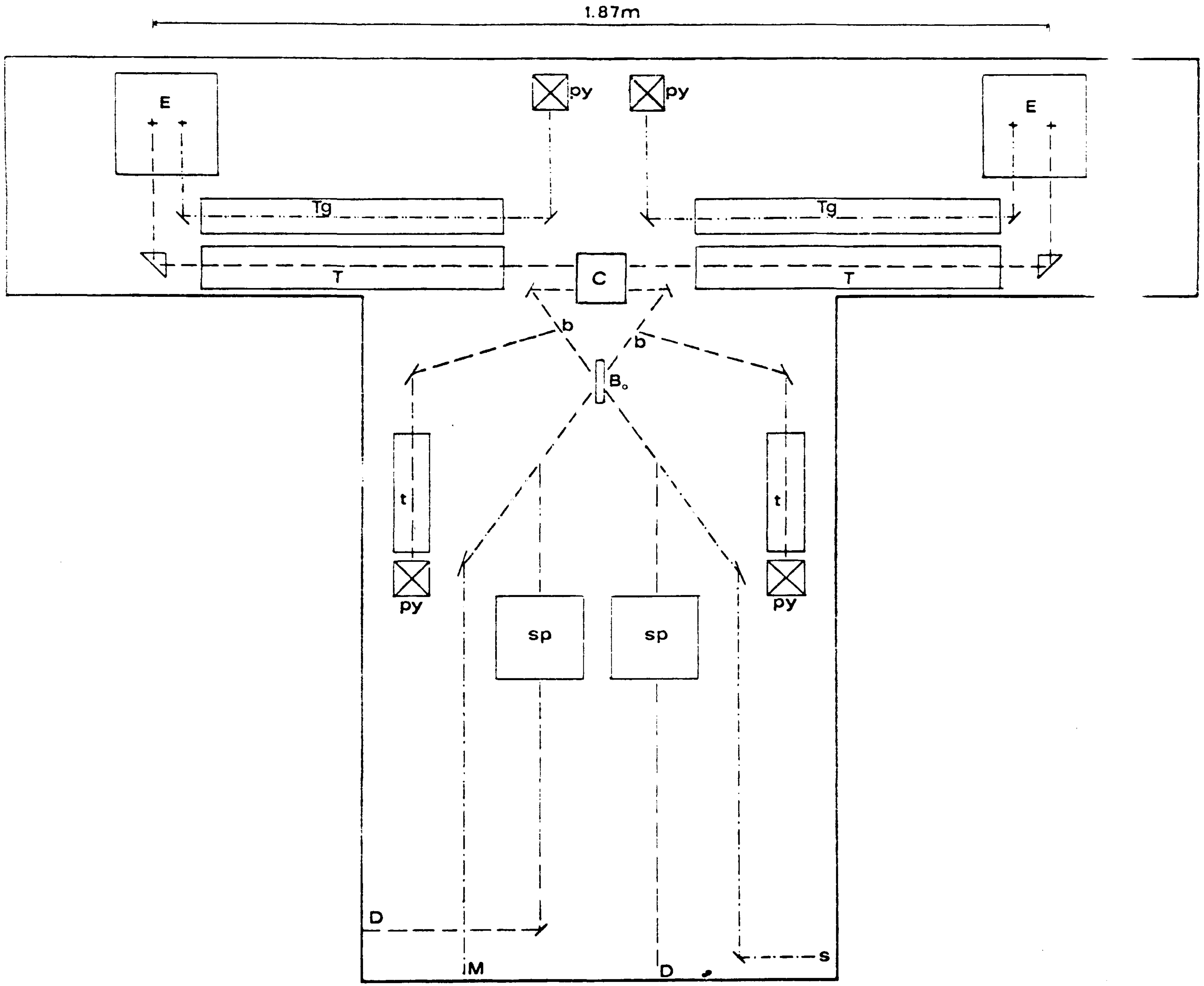

Figure 1. The optical layout of the interferometer. See text for explanation.

The entrance pupils of the interferometer are 45 mm in diameter. The achromatic telescopes T produce 15 mm beams which is directed first into a compensator C consisting of two cube corners. The compensator is used for equalizing the internal paths of the instrument and requires only occasional adjustment.

The remainder of the interferometer is very similar to the instrument described in the previous paper. The light is polarized by the beamsplitters b, it interferes at B_o, and after passing through prism spectrometers (sp) the light is finally detected by Channeltron photodetectors at D.

2.1 Angular tilt correction

An active optical system is used to ensure that the wavefronts interfere at zero angle. Long focus telescopes (t) and quadrant "optical pyramids" are used to drive horizontal and vertical "wobblers" located near the focus of the two refracting telescopes T. The wobblers consist of 10 mm thick plates of crown glass; these are suspended between jewel bearings and driven by moving coil actuators and stabilized by linear differential voltage transformers. These wobblers have a bandwidth of a few hundred Herz, but in practice the bandwidth was restricted to about 30 Hz because of noise considerations.

In addition to actuating the wobblers, the error signals from the quadrant detectors are sent to a power measuring circuit. This device measures the true mean square error signal, which is recorded digitally. This signal, which when calibrated is a measure of the loss of correlation due to residual tilt and the servo system noise, is used to correct the raw data from the interferometer correlator.

2.2 The correlator

The correlation is measured by counting the number of photons from the two Channeltron detectors which arrive in a sample time τ. After each period, the two numbers are summed into registers, the square of their difference is computed, and this too is summed into a register. After a total integration time T the three data are recorded for subsequent analysis. Both τ and T are variable. The reduction of the raw data is complicated by the fact that the counting statistics deviate somewhat from the ideal Poisson distribution. The apparent correlation resulting from the data reduction is finally corrected for losses due to seeing, using the error power signal from the "seeing" servo.

2.3 Optical alignment and figuring

The interferometer is aligned by means of an artificial star at s (Fig. 1). The light from this source is introduced into the main instrument by movable periscopes, and by this means one can adjust the optics without the need for starlight. Additionally, the elevation flats can be used with the artificial star to form a Twyman-Green interferometer. In this configuration one can readily equalize the internal path lengths by using a white light source at s.

As well, the Twyman-Green arrangement is used for overall figuring. Because of the number of surfaces in the interferometer, the wavefront distortion within the instrument was about 1 - 2 wavelengths. Correcting plates were placed in the two arms of the interferometer and these were figured *in situ* to reduce the total aberration to around $\lambda/10$.

3. RESULTS AND DISCUSSION

Interferometric observations began in mid-1976, but were terminated at the end of that year due to the closure of the station. Although the data are quite limited, the preliminary results are quite encouraging.

Observations on Vega (α Lyr) initially gave a low and variable fringe visibility. When the error monitoring electronics in the "seeing" servo were installed, it was possible to correct for the residual tracking errors and the correlation rose to 0.98 ± 0.02. The corrected correlation remained more or less steady during an observing session, although the raw fringe visibility varied considerably due to fluctuations in the "seeing." There appears to be no reason why the design magnitude limit of $m = \sim 6$

should not be reached, although instrumental difficulties restricted observations to only the brightest stars in 1976.

The limited data from Monteporzio indicates that a small aperture instrument is indeed practical. However, experience there has shown that great care must be taken to maximize the signal to noise ratio throughout the instrument, as the available light is restricted by the small apertures. With sufficient care and attention to detail one should be able to build such an interferometer with a limiting magnitude of $m \sim 8 - 9$.

REFERENCES

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2) K. Aa. Strand, "Trigonometric Stellar Parallaxes," in Basic Astronomical Data, 3, 55 (1963, Chicago), K. Aa. Strand, ed.
3) "Catalog of Bright Stars," (1964, Yale) D. Hoffleit, ed.
4) W. A. Cormack, J. Phys. E (GB), 7, 280 (1974).

DISCUSSION

D.L. Fried: It has been shown that there is a very high degree of correlation between the turbulence induced tilt over a circular aperture and that across a surrounding annulus. You could have used a 10 cm aperture and stripped off the outer 2.75 cm wide annulus to provide a better signal to noise ratio for the tilt servo, without diverting any of the light from the central 4.5 cm aperture, which all could be used to form the interference signal.

W.J. Tango: Yes. We are aware of this and will be looking at ways of using this effect in the future.

J.C. Dainty: At this resolution (2 m baseline) I would have thought that speckle interferometry using a low cost flux collector would be vastly superior for binary star observation.

W.J. Tango: Certainly the development of speckle interferometry over the last few years makes it attractive for relatively low resolution binary star work. However the Monteporzio interferometer is the only instrument designed solely for binary star work, which is important for discovery and survey programs.